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High Gradient Magnetic Separation Soil Treatability Study

From

Rocky Flats Operational Unit No. 2 Surficial Soil

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1.0 INTRODUCTION

1.1 SITE DESCRIPTION

1.1.1 Site Name and Description

Rocky Flats Environmental Technology Site (RFETS), a 6,550 acre industrial reservation is located in northern Jefferson County, Colorado RFETS lies on two major geological units unconsolidated surficial units (Rocky Flats Alluvium, various terrace alluvia, valley fill alluvium, and colluvium) underlain by Cretaceous bedrock (Arapahoe Formation, Laramie Formation, and Fox Hills Sandstone) Groundwater moves under confined conditions in surficial and shallow bedrock units Additionally, confined groundwater flow occurs in deeper bedrock sandstones Surficial soils are predominantly moderately deep to deep, well-drained clay loams of moderate to low permeability (Final Phase II RCRA Facility Investigation Remedial Investigation, Work Plan [Alluvial], U S Department of Energy, Rocky Flats Office, Golden, Colorado, 29 February 1991)

1.1.2 History of Operation

From the mid-1950s to the present, RFETS has been a government-owned (U S Department of Energy [DOE]), contractor-operated facility that fabricated nuclear weapon components from plutonium (Pu), uranium (U), and other non-radioactive metals (principally beryllium (Be) and stainless steel) Plutonium was also recovered in the facility when it reprocessed components after they were removed from obsolete weapons

1.2 WASTE STREAM DESCRIPTION

1.2.1 Production Wastes

Radioactive and nonradioactive wastes were generated in the production processes Plant waste handling practices involved onsite and offsite recycling of hazardous materials, onsite storage of hazardous and radioactive mixed wastes, and offsite disposal of solid radioactive materials at other DOE facilities In the past, hazardous, radioactive, and radioactive mixed wastes were stored onsite Primary assessments under environmental remediation programs have identified some of these storage and disposal locations as potential sources of environmental contamination

1.2.2 Pollutants/Chemicals

The 903 Pad, located on the south eastern side of the plant, is a portion of Operable Unit No 2 (OU2) and covers an area 113 meters wide by 120 meters long In 1958, waste drums were stored at this location Contaminated soil was first discovered in 1964 in an area where 210 liter drums of plutonium-laden lathe coolant oil were stored. The drums contained cutting oil and carbon tetrachloride contaminated with plutonium and uranium cuttings from nuclear weapons components machining operations

By 1968, all of the drums had been removed, processed, and shipped offsite for disposal The contaminated area was covered with a pad consisting of successive layers of fill dirt, gravel, and a final layer of asphalt The level of contamination in the soil ranged between 2,000 to 300,000 disintegrations per minute (dpm)/100 square centimeters (cm^2), with penetration depths of 3 to 20 cm The plutonium metal was originally deposited as fine metallics It oxidized into PuO_2 in the environment The average size of the PuO_2 particles was 0 2 microns (Soil Decontamination Criteria Report, J A Hayden, et al, Rockwell International, November, 1990)

1.2.3 Treatability Study Background

This study was undertaken to evaluate the effectiveness of High Gradient Magnetic Separation, HGMS in removing actinides from RF-OU2 soils A treatability study was conducted by LESAT (Plutonium in Soils Treatability Studies, RF-OU2, T K Wenstrand and T M Murarik, Lockheed Environmental Systems and Technologies Co , Sept 30, 1993) to evaluate the effectiveness of the TRUclean gravity separation process in removing activity from RF-OU2 soils This report describes all aspects of the Physical Separation Treatability Test, including operating features of the TRUclean process Because of the appropriateness of HGMS in treating small particle contamination, a residue from the TRUclean process was selected for HGMS evaluation (Sample 6 in the above referenced report) The HGMS technology is viewed as a natural complement to soil washing and gravity separation.

1.3 TREATMENT TECHNOLOGY DESCRIPTION

1.3.1 Treatment Process, Description, and Operating Features

HGMS is a form of magnetic separation in which large magnetic field gradients are used to separate micron sized paramagnetic particles The HGMS separator consists of a high-field, superconducting solenoid magnet, where the bore of the magnet contains a fine structured matrix material The matrix material (usually ferromagnetic) locally distorts the magnetic field and creates large field gradients in the vicinity of the matrix elements These matrix elements become the trapping sites for both paramagnetic and ferromagnetic particles When the field gradients are sufficiently high , weakly paramagnetic particles can be physically captured and separated from diamagnetic host materials Because most actinide compounds are paramagnetic, magnetic separation of actinide containing mixtures is feasible

The application of HGMS involves passing a slurry of the contaminated mixture through a magnetized volume Ferromagnetic and paramagnetic particles are extracted from the slurry by the ferromagnetic matrix while the diamagnetic fraction passes through the magnetized volume The magnetic fraction is flushed from the matrix later when the magnetic field is reduced to zero or the matrix is removed from the magnetized volume The actinide containing concentrate can then be processed for disposal

Field?

The slurry was pumped through the magnetic matrix using a peristaltic pump at constant flowrate Feed slurry homogeneity was maintained using a mixer at the pump inlet Back-flushing of the magnetic matrix was done at zero magnetic field and with the flow direction reversed Feed backflush and multipass effluent samples were analyzed for contaminant concentration Samples are analyzed for plutonium concentration using alpha spectroscopy

1.4 Previous Treatability Studies at the Site

In addition to the LESAT Report, another soils treatability study was reported in August, 1994 entitled, "Rocky Flats Plant Soil Treatment Bench-Scale Treatability Studies (Nuclear Remediation Technologies Division, General Atomics-San Diego, California, GA-C21818) This study reported on preliminary characterization, flotation/attrition scrubbing tests, and leaching tests

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2.0 CONCLUSIONS AND RECOMMENDATIONS

2.1 CONCLUSIONS

This physical separation, soil treatability study evaluated the effectiveness of using High Gradient Magnetic Separation, HGMS to treat TRUclean process residues for removal of actinides Several separator operating parameters including superficial velocity, applied magnetic field and matrix packing density were systematically investigated along with various pretreatment protocols The pretreatment protocols included pH adjustment, surfactant variation and organic destruction using an oxidizing agent, H_2O_2

The objective of any physical separation process is to concentrate the most contaminant into the smallest fraction of the feed Therefore, results which show high separation efficiencies along with high mass fractions in the contaminant stream are undesirable. This study showed that HGMS can achieve significant separation of actinides from the processed soil residues investigated A concentration of 51% of the activity in only 2% of the feed was achieved based on analysis of the feed and effluent

2.2 RECOMMENDATIONS

2.2.1 Additional Studies

In view of the large number of parameters affecting the HGMS process and the complexity of the evaluation procedure, results from this initial study should be viewed as preliminary Time was not available to repeat those particular runs in this study which demonstrated significant separation or to conduct additional tests based on conclusions reached at the end of this evaluation

Additional studies that focus on the operating regime and pretreatment protocol of choice for this application are necessary In conjunction with the LANL analytical model of the HGMS process, these additional data will form the basis for the scale-up to a prototype system

HGMS is an effective physical separation process for removing small particle contamination (<100 µm) Most soil washing methods are only effective on particles greater than 50 to 100 µm. Although these traditional treatments can be effective in removing large particle contamination, their application frequently transports a significant portion of the contaminant into the fines Once there, the contaminant is more difficult to remove and frequently requires a costly chemical treatment to reach remediation targets As shown by this study, HGMS can be effective in treating the fines by physical separation and offers the potential to treat the bulk of the contaminated soil using physical separation methods HGMS has been demonstrated on an industrial scale in the processing of kaolin clay and is cost effective in treating large volumes of material to remove small amounts of contaminants

3.0 TREATABILITY STUDY APPROACH

3.1 TEST OBJECTIVES AND RATIONALE

Magnetic separation has been shown to be effective at removing small particle size contaminants (<50 µm) from similar small sized particle slurries Because of this, magnetic separation is thought to be a compatible technology with soil washing which is appropriate for treating larger particles (>50 µm) Frequently, treatment of the larger particles using conventional technologies results in migration of the contaminant to a smaller size fraction of the waste stream Consequently the fines are usually enriched by the contaminant. Magnetic separation is one of the few physical separation processes that is capable of treating this fine fraction As a result, a treated waste stream residue was selected as an appropriate feed material for the magnetic separation treatability study The thickener underflow from the LESAT processing circuit (<150 µm) was eventually selected Activity levels of this material ranged from 100 to 144 pCi/g The material was sieved using a 325 mesh screen to less than 53 µm

The objective of the treatability study was to evaluate the effectiveness of HGMS in removing actinide contamination from the LESAT treatment residues Table 3 1-1 summarizes the experiment series by run

The objectives were as follows

Series 1 (Runs 701-705), Explore sensitivity to magnetic field Determine the effect of concentration of sodium hexametaphosphate and the influence of superficial velocity on separation performance

Series 2 (Runs 706-709), Determine the effect of pH and H_2O_2 pretreatment on separation performance Also a scalping pass with a paramagnetic matrix at 2 0 Tesla was introduced Maximum field reduced to 2.0 T

Series 3 (Run 710-713), Combine the scalping pass with a low field ferromagnetic pass. Investigate the effect of an alternate surfactant and lower solids fraction

Table 3.1-1 HGMS Experiment Parameters

Series	Run #	Magnetic Field (T)	Uo[1] (cm/s)	Surfactant	pH	Sonicate	Matrix
1	701	0 5/6 5	0 5	0 2 % Hexamet[2]	10	yes	VI
1	702	0 5/6 5	0 5	none	8	yes	VI
1	703	0 5/6 5	0 5	0 05 % Hexamet	8	yes	VI
1	704	0.5/6 5	0 25	0 05 % Hexamet	8	yes	VI
1	705	0.5/6 5	1 0	0.05 % Hexamet	8	yes	VI
2	706	2 0p[3]/2 0	0 5	0 2 % Hexamet	8	yes	VII/VI
2	707	2.0p/2 0	0 5	0 2 % Hexamet	10	yes	VII/VI
2	708	2p/2 0/6 5	0 5	0 2 % Hexamet	12	yes	VII/VI
2	709*	2.0p/2 0	0.5	0 2 % Hexamet	10	yes	VII/VI
3	710	2p/0 5/6 5	0.5	0 2 % Hexamet	10	yes	VII/VIII
3	711	2p/0 5/6 5	0 5	0 2 % Hexamet	10	yes	VII/VIII
3	712[4]	2p/0 5/6 5	0 5	0 2 % Hexamet	10	yes	VII/VIII
3	713	2p/0 5/6 5	0 5	Alternative Surfactant	10	yes	VII/VIII

[1]Superficial velocity
[2]Sodium Hexametaphosphate
[3]Paramagnetic matrix
[4]Pretreat with H_2O_2

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3.2 Experimental Design and Procedure

Experiments were run at the LANL plutonium facility (TA-55) in PF-4, Rm 128 In Rm 128 the HGMS unit is mounted atop a vent hood

Residue samples were wet sieved <53µm, slurried to a specified solids content (typically 10 wt%), treated with surfactant, pH adjusted with sodium hydroxide and bulk sonicated to insure particle deagglomeration The sample was then further treated depending upon test protocol to improve particle liberation.

The test protocol required rinsing of the ferromagnetic matrix with a solution of identical pH and surfactant concentration as the test slurry The pretreatment was followed by pass 1 of the test slurry Upon completion of pass 1, the matrix was rinsed at field and then backflushed at zero field The magnetics were recovered prior to pass 2. The effluent from pass 1 was then used as the feed for pass 2 The process was repeated for additional passes as desired

3.3 Equipment and Materials

Add Source? Equipment/process

3.3.1 OK Magnetic Separator

The magnetic separator consists of a solonoidal, superconducting magnet with a room temperature bore located outside the cryogenic space The superconducting magnet is maintained at 4 2 K and can generate a magnetic field strength as high as 8 T within the warm bore A stainless steel tube, capped at one end, extends out the top of the hood and fits into the warm bore of the magnet The magnet is external to the hood but the high magnetic field region can be accessed from within the hood via the blind tube

3.3.2 Test Canister-

The test canister holds either a ferromagnetic or paramagnetic matrix and provides flow deceleration zones for the slurry and backflush Flex hoses are attached to each end of the canister permitting the canister to be removed from the magnet bore without exposing the slurry

3.3.3 Peristaltic Pump

Fluids were pumped through the test canister with a peristaltic pump Because the pump operates by pinching the flex tube with rotating rollers, cross contamination between the various flow streams is minimized The pump is easily calibrated and the flow direction can be reversed

3.4 Sampling and Analysis

The treated slurry is pumped through the magnetic separator The emerging effluent is the decontaminated stream, whereas, the material retained by the separator is the magnetic fraction After processing the sample, the magnetically trapped material was rinsed from the separator in a backflush operation outside the magnetic field. Feed slurry homogeneity was maintained using a mixer at the pump inlet. Feed and multipass effluent samples were analyzed for contaminant concentration Samples were taken in test series 1 (701-705) by mixing the effluent and pouring a sample from the collection bottle Samples were taken in test series 2 and 3 (706-709 and 710-713) by mixing the effluent in a squirt bottle and then discharging the sample from the bottom fed discharge tube This procedure was an attempt to homogenize the effluent before sampling All samples were collected in tared glass bottles then subsequently dried and weighed to provide data for a mass balance Dried samples were analyzed for plutonium concentration using alpha spectroscopy by either Controls for Environmental Pollution (CEP), Santa Fe, NM (701-709) or Lockheed Analytical Services (LAS), Las Vegas, NV (710-713).

CEP and LAS both followed similar procedures for alpha spectroscopy Received samples were quantitatively transferred to digestion beakers by acid rinsing of the sample bottles A plutonium-242 tracer was added then the total sample was digested with nitric acid and hydrofluoric acid LAS used microwave digestion A boric acid or perchloric acid solution was added to the soil residue to convert the plutonium to a +4 valence state LAS concentrated the plutonium by adding a ferric standard solution then ammonium hydroxide to the digested solid sample to precipitate ferric hydroxide with the plutonium LAS then collected and dissolved this solid with nitric acid The sample was then passed through an anion exchange column, washed, and the plutonium eluted LAS proceeded with a Nd^{3+} microprecipitation of the plutonium and collection on a 0 2 mm membrane filter, CEP proceeded with electroplating of the plutonium on stainless steel discs The filters or discs were then counted by alpha spectroscopy

3.5 Data Management

This treatability study was conducted to evaluate the feasibility of using HGMS to address RF soil remediation It was conducted in accordance with applicable LANL procedures and practices governing the conduct of operations of the magnetic separation equipment Procedures have been established that govern the conduct of HGMS experiments including safe operating procedures, data handling and documentation

Experiment flowsheets were prepared and reviewed prior to all HGMS tests Using these flowsheets, a test specification sheet was generated assigning experiment identification numbers and defining equipment settings for the proposed test Sample identification labels were generated for all sample containers and sample locations were identified on the experiment flowsheet Samples were collected in labeled, tared sample bottles, for oven drying and weighing All samples were maintained in their original, labeled sample containers

4.0 RESULTS AND DISCUSSION

4.1 DATA ANALYSIS AND INTERPRETATION

4.1.1 Analysis of Waste Stream Characteristics

As discussed in 3 1 activity levels of the treated material ranged from 100 to 144 pCi/g Particle sizes were less than 53 µm More detailed information on the generation of this residue can be obtained from the LESAT Report cited in 1 2 3

4.1.2 Treatability Study Objectives

The magnetic separation process has a number of variables which influence the results These are listed in table 4 1 2-1 where they are categorized according to material characteristics or separator characteristics In general, the material characteristics are determined by the application, i.e , the type of soil, the contaminant and its distribution, the particle sizes and the physical properties Some material characteristics are controllable, such as, surfactant type and concentration, and solids concentration However, the separator parameters are where most of the process control exists These parameters are controlled by the matrix design, the magnetic field characteristics and the slurry fluid mechanics It is necessary to select a set of operating parameters that are compatible with the contaminated medium and that maximize the magnetic separation process

Table 4.1.2-1 HGMS Experiment Parameters

Material Characteristics	Separator Parameters
Particle Size 0 5 - 50 µm	Matrix Element Size 5 - 100 µm
Impurity Concentration 0 4 - 2000 ppm	Matrix Element Spacing 80 - 1200 µm
Solids Concentration 5 - 30 wt %	Magnetic Field Strength 0 5 - 7 5 T
Magnetic Susceptibility* ($x10^6$) 129 - 1478	Matrix Material 430 Stainless Steel
Surfactant Concentration 0 00 - 0 2 wt %	Residence Time 1 0 - 8 0 s
Slurry pH 4 - 12	Superficial Velocity 0 25 - 4 0 cm/s

* SI units

In conducting the treatability study for the Rocky Flats soil residue three series of tests were conducted to cover the HGMS performance envelope. These tests, defined in 3 1, were used to generate an HGMS performance map for RF residue as shown in fig 4 1 2-1 Test series 1 addressed the full field strength range of the magnetic separator while using a ferromagnetic matrix These results showed the largest separation efficiencies The mass fraction retained by the matrix increases nearly linearly with increasing applied magnetic field reaching 0 3 at the 6 5 T pass In test series 2, a paramagnetic scalping pass at 2 0 T was introduced in an attempt to reduce the magnetic fraction of the soil In this series the second pass was done at 2 T using the ferromagnetic matrix. This series also investigated the effect of pH Test series 3 also started with the paramagnetic scalping pass but pass 2 was executed at 0 5 T with the ferromagnetic matrix in an attempt to reduce the mass fraction retained by the matrix This was followed by a third pass at 6 5 T.

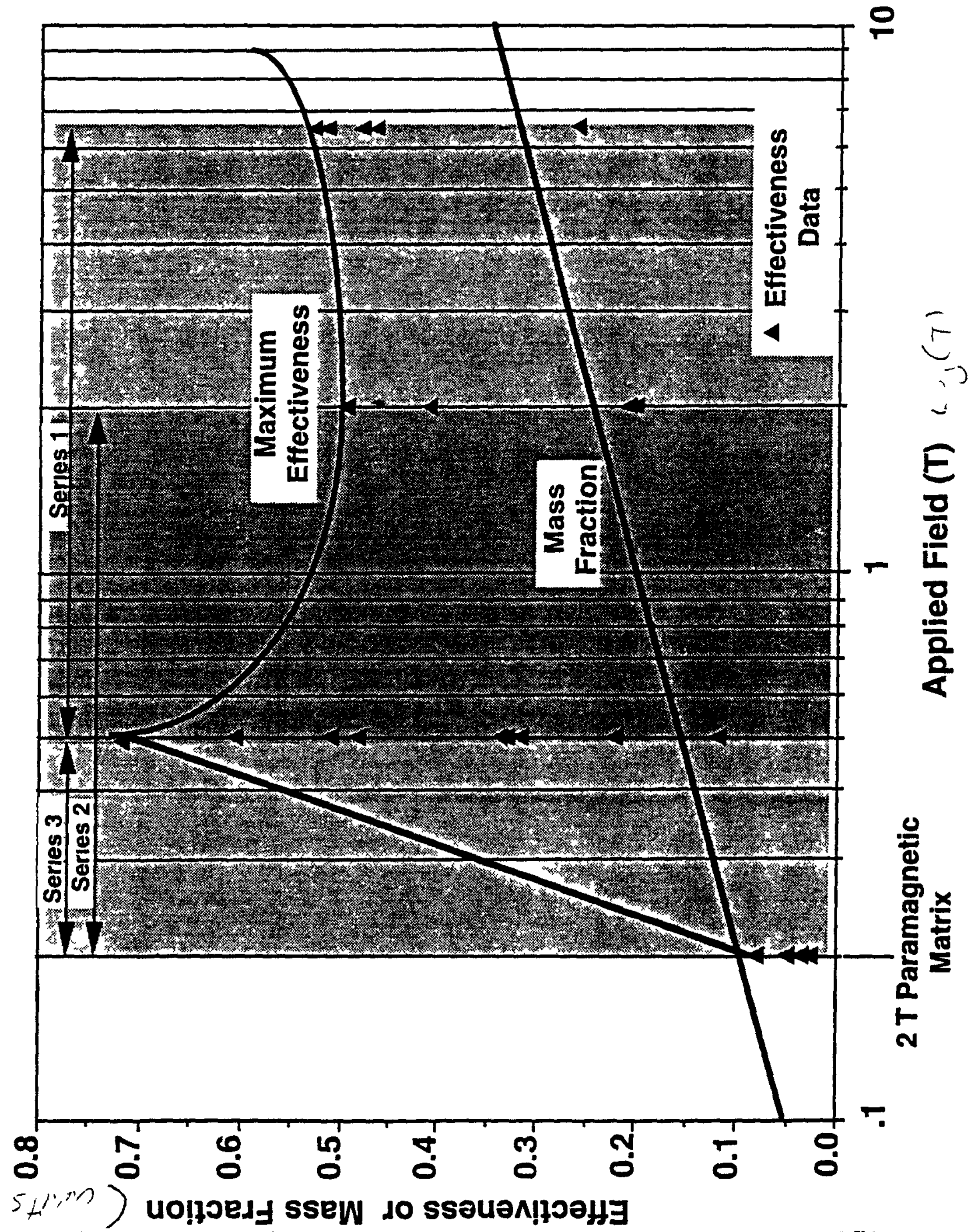

Fig. 4.1.2-1. HGMS Performance Map for RF Soil Residue (LESAT) Showing Mass Fraction Retained and Separation Efficiency.

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4.1.3 Treatability Study Results

Appendix A contains the flow diagrams and detailed data sheets for each run. There is a separate flow diagram for each test series showing the parameters for each run in the series and the location and identification of each sample taken The mass and activity for each sample analyzed (in bold) and certain derived values (plain text) are also included and grouped by series The mass weighted specific activity, which is the product of the mass fraction and the specific activity, is used to determine separation efficiency The separation efficiency is calculated three ways using the mass weighted specific activity from either the feed and backflush, the backflush and effluent or the feed and effluent If the mass and activity balance error were both zero, all three methods would give the same result However, because of difficulties with either incomplete flushing of the matrix or inhomogeneous sampling of the effluent, one of these methods is usually more appropriate than the others

In test series 1, the system activity balance indicated that backflushing of the matrix to remove the magnetic fraction was incomplete The incomplete backflush was later verified by surrogate tests using the same test protocol Therefore, separation efficiencies calculated using feed and effluent concentrations are probably more accurate than if the backflush concentrations were used Several procedural changes were implemented in test series 2 and 3 in an attempt to improve the activity balances for these later tests Backflushing was improved by incorporating air sparging into the liquid flush By introducing bubbles into the flow stream, the scavenging of trapped material was improved and most of the material was liberated In addition, effluents were sampled using bottom taps installed on the sample bottles This modification in conjunction with the swirling motion employed to maintain particle suspension, appears to have resulted in a nonhomogeneous sampling of the effluent by preferentially collecting the heavier components containing higher activity from the mixture Therefore, in test series 2 and 3 the feeds and backflushes had greater accuracy than the effluent samples, and efficiencies for these runs were calculated using the feed and backflush concentrations In general, activity balances were improved in the latter experiments with errors being less than ±20% Table 4 1 3-1 is a results summary of the HGMS experiments Included are the mass fractions and activity fractions for each pass of each run

4.1.3.1 Test Series 1

The following observations were made from test series 1

a There is a high magnetic fraction in the soil residue Even at B=0 5 T, the mass fraction retained by the matrix is high

b High pH (>10) appears to aid dispersion and reduces matrix loading (see Run 701).

c Surfactant concentrations approaching 0 2 wt% may be necessary to insure high dispersion

d Low superficial velocities (<0 5 cm/s) that normally improve separation efficiency result in unacceptably high mass retention in the matrix. (Run 704)

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e Run 705 at superficial velocity of 1 0 cm/s showed an unexpectedly high separation effectiveness

f Activity balance adversely affected by incomplete backflushing of the matrix

4.1.3.2 Test Series 2

The analysis for series 2 includes the addition of a "forward flush" which is a rinse of the matrix at field to remove solids before the backflush Although assayed separately, it is assumed to be part of the effluent stream when calculating effectiveness Several modifications to the test procedure were incorporated into series 2 as follows

a Modify sampling of the feed to assure sample uniformity

b Backflush matrix with air sparge to improve material recovery

c Install bottom taps on sample bottles to improve homogeneity in sampling

d Adjust backflush solution to pH12

Results of test series 2 are as follows

a The scalping passes were successful in removing magnetic soil components and did not include significant activity

b Pass 2 with the ferromagnetic matrix at 2 0 T resulted in significant mass retention along with activity removal

c Organic destruction by peroxide pretreatment (Run 709) appears to enhance liberation of the paramagnetic actinides Compared with Run 707, more activity was removed in the scalping pass after H_2O_2 pretreatment However, the effect is not significant

4.1.3.3 Test Series 3

Recognizing that the separation results from series 1 at B=0.5 T were better than series 2 results at 2 0 T, series 3 included a scalping pass at 2 0 T followed by a ferromagnetic pass at 0 5 T Reduced solids fraction was investigated to evaluate the effect of particle interference In addition, the H_2O_2 pretreatment was repeated along with a run to evaluate a second surfactant, sodium silicate The procedural modifications used in series 2 were continued for series 3 (the effluent sampling problem was not discovered until after test series 3 was completed)

Results of test series 3 are as follows

a The scalping pass again extracted approximately 10% of the soil without removing appreciable activity

b Mass fractions from the second pass (B=0 5 T) were higher than observed in series 1 Therefore, the scalping pass employed in this series may not be desirable

c Reduced solids fraction increased both separation efficiency and mass retention with no net benefit

d The H_2O_2 pretreatment was ineffective in improving separation

e The use of sodium silicate as a surfactant significantly increased separation efficiency (from 0 22 to 0 48) with only a slight increase in mass retention (from 0 18 to 0 26)

Table 4.1.3-1 HGMS Results Summary

Series	Run #	Magnetic Field (T)	Surfactant	pH	Mass Fraction	Effectiveness per Pass
1	701	0 5/6 5	0 2 % Hexamet	10	.021/ 234	511/ 466
1	702	0.5/6 5	none	8	.067/.203	307/ 371
1	703	0 5/6 5	0 05 % Hexamet	8	071/.184	314/ 435
1	704	0 5/6 5	0.05 % Hexamet	8	130/.202	693/ 112
1	705	0 5/6 5	0.05 % Hexamet	8	056/ 151	595/ 165
2	706	2 0p/2.0	0 2 % Hexamet	8	081/ 299	.023/ 494
2	707	2 0p/2 0	0 2 % Hexamet	10	091/ 228	031/ 209
2	708	2p/2 0/6 5	0 2 % Hexamet	12	050/ 217	035/.200
2	709*	2 0p/2 0	0.2 % Hexamet	10	056/ 267	028/.409
3	710	2p/0 5/6.5	0.2 % Hexamet	10	.110/ 176	081/ 220
3	711	2p/0 5/6.5	0 2 % Hexamet	10	123/ 284	052/.317
3	712*	2p/0 5/6 5	0 2 % Hexamet	10	083/ 181	037/ 118
3	713	2p/0 5/6 5	0.5% Na_2SiO_3	10	111/ 264	078/ 481

* Pretreat with H_2O_2

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4.2 QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

QA/QC were maintained through data documentation as described in Section 3 5, Data Management

Appendix A: Acronym List

Be	Beryllium
CEP	Controls for Environmental Pollution
cm	centimeters
cm^2	square centimeters
DOE	Department of Energy
dpm	Disentegrations per Minute
HGMS	High Gradient Magnetic Separation
H_2O_2	Peroxide
K	Kelvin
LAS	Lockheed Analytical Services
LANL	Los Alamos National Laboratory
LESAT	Lockheed Environmental Systems and Technology Co
Na_2SiO_3	Sodium Silicate
Nd	Neodymium
OU	Operable Unit
pCi/g	Pico Curies Per Gram
PF	Plutonium Facility
Pu	Plutonium
PuO_2	Plutonium oxide
QA	Quality Assurance
QC	Quality Control
RCRA	Resource Conservation and Recovery Act
RF	Rocky Flats
RFP	Rocky Flats Plant
RFETS	Rocky Flats Environmental Technology Site
TA	Technical Area

18

U	Uranium
µm	Micrometers

MAGNETIC SEPARATION TEST

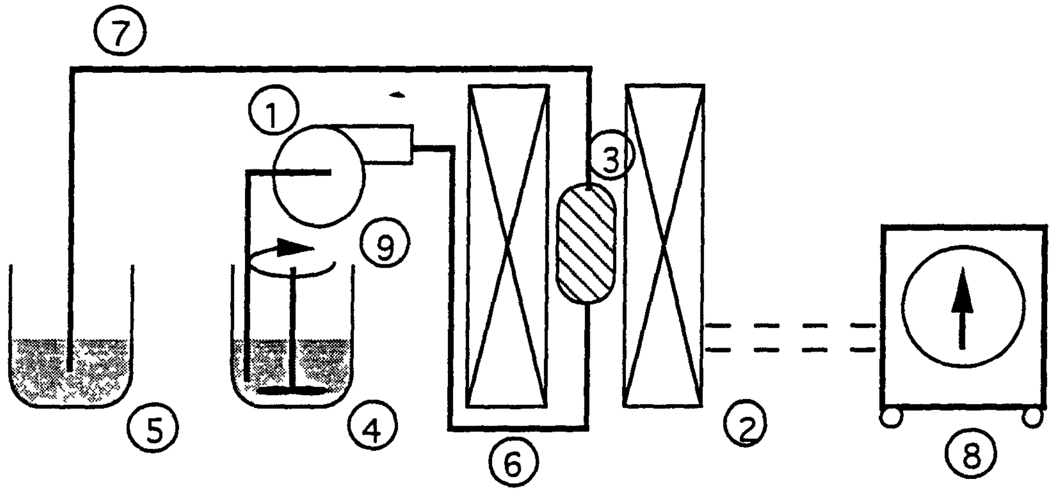
Date- 2/10 & 17/94 Location-TA55/PF4/RM128

Separator-

Type	Magnet	Manufacturer	Descriptor
HGMS	3" Superconductor	Cryomagnetics	Internal

Objective-Test Series 1

Experimental Schematic-



(1) Monostat D Series Varistatlic pump calibrated for tubing with 4 layers of tape in tube tray and foam to center tubing in tray
(2) Cyomagnetics 3" warm bore S/C magnetic separator
(3) Matrix
(4) Supply beaker
(5) Exit and sample beaker
(6) Nalgene tubing 1/8" ID
(7) Nalgene tubing 1/8" ID
(8) Magnet power supply
(9) Stirrer

MAGNETIC SEPARATION TEST　　　RFP Soil LESAT Residue

Date　2/10/94 & 2/17/94

Carrier Flui

Description
DI H2O

Surrogate

Description	Particle Size
LESAT Thickner Underflow	<53u

Matrix

Matrix #VI

Comments

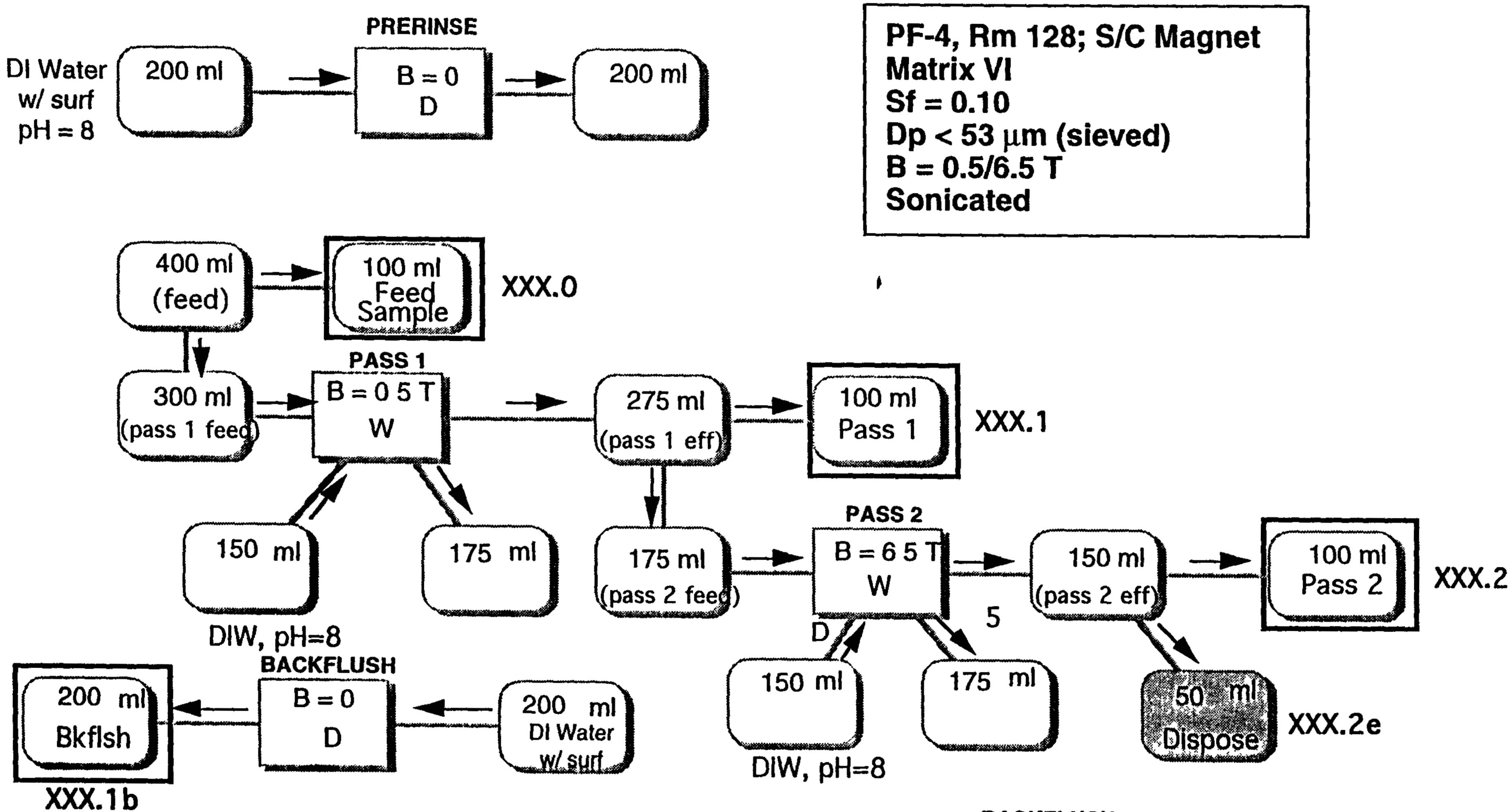
Test	Surf	pH
701	2% HEX	10
702	0	8
703	05% HEX	8
704	05% HEX	8
705	05% HEX	8

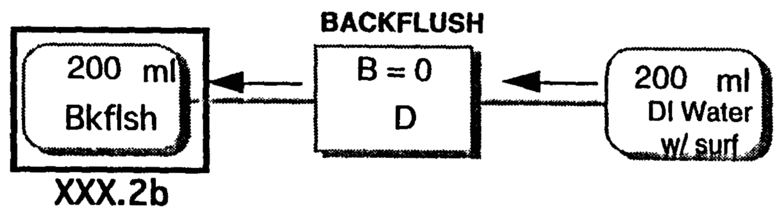
DATA

Test #	Pass #	Displayed Flow Rate (ml/s)	Corrected Flow Rate (ml/s)	Magnet Current (A)	Field Strength (Tesla)	Solids Conc (%)	Temp (C)	Flow Direction
701 0	0	-	-	0	0	10%	20	-
701 1	1	70	1 35	56	0 5	10%	20	D
701 2	2	70	1 35	56	6 5	10%	20	D
701 2b	2	400	7 5	0	0	10%	20	U
702 0	0	-	-	0	0	10%	20	-
702 1	1	70	1 35	56	0 5	10%	20	D
702 1b	1	400	7 5	0	0	10%	20	U
702 2	2	70	1 35	56	6 5	10%	20	D
702 2b	2	400	7 5	0	0	10%	20	U
703 0	0	-	-	0	0	10%	20	-
703 1	1	70	1 35	56	0 5	10%	20	D
703 1b	1	400	7 5	0	0	10%	20	U
703 2	2	70	1 35	56	6 5	10%	20	D
703 2b	2	400	7 5	0	0	10%	20	U
704 0	0	-	-	0	0	10%	20	-
704 1	1	35	0 675	56	0 5	10%	20	D
704 1b	1	400	7 5	0	0	10%	20	U
704 2	2	35	0 675	56	6 5	10%	20	D
704 2b	2	400	7 5	0	0	10%	20	U
705 0	0	-	-	0	0	10%	20	-
705 1	1	140	2 7	56	0 5	10%	20	D
705 1b	1	400	7 5	0	0	10%	20	U
705 2	2	140	2 7	56	6 5	10%	20	D
705 2b	2	400	7 5	0	0	10%	20	U

2/10&17/94 RFP Sample (LESAT Residue - Thickener underflow)

Determine effect of flowrate and surfactant





Run#	B (T)	pH	Surf	Uo (cm/s)
701	0.5/6.5	10	0.2% Hex	0.5
702	0.5/6.5	8	none	0.5
703	0.5/6.5	8	0.05% Hex	0.5
704	0.5/6.5	8	0.05% Hex	0.25
705	0.5/6.5	8	0.05% Hex	1.0

Sample	Weight	Mass Balance Error	Mass Fraction	Specific Activity	Activity	Activity Balance Error	Mass Weighted Specific Activity	Separation Efficiency* Using		
	(g)	(%)		(pCi/g)	(pCi)	(%)	(pCi/g)	feed & bk	bk & effl	feed & effl
Run #701										
feed	37 7			120 00	4524 00					
XXX.0	9 6			120 00	1152 00					
Pass 1 feed	28 1		1 000	120 00	3372 00		120 000			
XXX.1	9 1			60	546 00					
XXX.1b	0 6		0 021	248	148 80		5 295	0 044	0 083	0 511
Pass 1 eff	27 5		0 979	60	1650 00		58 719			
Pass 2 feed	18 4		1 000	60	1104 00		60 000			
XXX.2	7 2			41 8	300 96					
XXX 2b	4 3		0 234	112 20	482 46		26 221	0 224	0 450	0 466
Pass 2 eff	14 1		0 766	41 80	589 38		32 032			
XXX 2e	7			41 8	292 60					
Total	37 8	0 27	**0.255**		2922 82	-35 39		0 258	0 496	0 739
Run #702										
feed	40			99 50	3980 00					
XXX.0	5 6			99 50	557 20					
Pass 1 feed	34 4		1 000	99 50	3422 80		99 500			
XXX 1	5 02			73 9	370 98					
XXX.1b	2 3		0 067	189	434 70		12 637	0 127	0 155	0 307
Pass 1 eff	32 1		0 933	73 9	2372 19		68 959			
Pass 2 feed	27 08		1 000	73 9	2001 21		73 900			
XXX 2	1 7			58 3	99 11					
XXX.2b	5 5		0 203	114 70	630 85		23 296	0 250	0 334	0 371
Pass 2 eff	21 58		0 797	58 30	1258 11		46 459			
XXX.2e	8			58 30	466 40					
Total	28 12	-29 70	**0 270**		2559 24	-35 70		0 345	0 437	0 564
Run #703										
feed	40			100	4000 00					
XXX 0	6 1			100	610 00					
Pass 1 feed	33 9		1 000	100	3390 00		100 000			
XXX 1	5 4			73 8	398 52					
XXX.1b	2 4		0 071	175	420 00		12 389	0 124	0 153	0 314
Pass 1 eff	31 5		0 929	73 8	2324 70		68 575			
Pass 2 feed	26 1		1 000	73 8	1926 18		73 800			
XXX 2	2 4			51 1	122 64					
XXX.2b	4 8		0 184	144 30	692 64		26 538	0 281	0 389	0 435
Pass 2 eff	21 3		0 816	51 10	1088 43		41 702			
XXX.2e	6 5			51 10	332.15					
Total	27 6	-31 00	**0.255**		2575 95	-35 60		0 370	0 482	0 613

23

Sample	Weight (g)	Mass Balance Error (%)	Mass Fraction	Specific Activity (pCi/g)	Activity (pCi)	Activity Balance Error (%)	Mass Weighted Specific Activity (pCi/g)	Separation Efficiency* Using feed & bk	bk & effl	feed & effl
Run #704										
feed	40			140	5600 00					
XXX.0	5 3			140	742 00					
Pass 1 feed	34 7		1 000	140	4858 00		140 000			
XXX 1	5			49 4	247 00					
XXX 1b	4 5		0 130	124 7	561 15		16 171	0 116	0 273	0 693
Pass 1 eff	30 2		0 870	49 4	1491 88		42 994			
Pass 2 feed	25 2		1 000	49 4	1244 88		49 400			
XXX 2	1 7			55	93 50					
XXX.2b	5 1		0 202	129 90	662 49		26 289	0 185	0 375	0 112
Pass 2 eff	20 1		0 798	55 00	1105 50		43 869			
XXX.2e	6 9			55 00	379 50					
Total	28 5	-28 75	**0.332**		2685 64	-52 04		0 279	0 546	0 727
Run #705										
feed	40			144	5760 00					
XXX 0	6		-	144	864 00					
Pass 1 feed	34		1 000	144	4896 00		144 000			
XXX.1	6 9			61 8	426 42					
XXX 1b	1 9		0 056	233 2	443 08		13 032	0 090	0 183	0 595
Pass 1 eff	32 1		0 944	61 8	1983 78		58 346			
Pass 2 feed	25 2		1 000	61 8	1557 36		61 800			
XXX.2	3 2			60 79	194 53					
XXX 2b	3 8		0 151	168 90	641 82		25 469	0 184	0 330	0 165
Pass 2 eff	21 4		0 849	60 79	1300 91		51 623			
XXX.2e	6 9			60 79	419 45					
Total	28 7	-28 25	**0 207**		2989 30	-48 10		0 257	0 453	0 662

$$*\frac{(\text{Mass Fraction} * \text{Specific Activity})_{mags}}{(\text{Mass Fraction} * \text{Specific Activity})_{feed}}$$

Combined efficiencies are calculated using Etot = E1 + E2 - E1*E2

MAGNETIC SEPARATION TEST

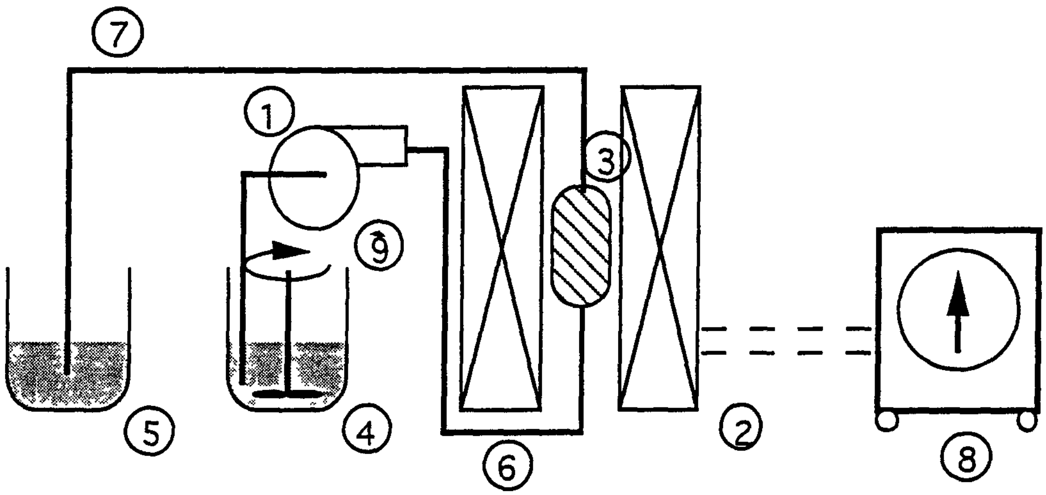
Date- 7/14/94 Location-TA55/PF4/RM128

Separator-

Type	Magnet	Manufacturer	Descriptor
HGMS	3" Superconductor	Cryomagnetics	Internal

Objective-Test Series 2

Experimental Schematic-



(1) Monostat D Series Varistatlic pump calibrated for tubing with 4 layers of tape in tube tray and foam to center tubing in tray
(2) Cyomagnetics 3" warm bore S/C magnetic separator
(3) Matrix
(4) Supply beaker
(5) Exit and sample beaker
(6) Nalgene tubing 1/8" ID
(7) Nalgene tubing 1/8" ID
(8) Magnet power supply
(9) Stirrer

MAGNETIC SEPARATION TEST RFP Soil LESAT Residue

Date 7/15/94

Carrier Flui

Description
DI H2O

Surrogate

Description	Particle Size
LESAT Thickner Underflow	<53u

Matrix

pass 1 Matrix VII
pass 2 Matri VI

Comments

Test	pH
706	8
707	10
708	12
709	10

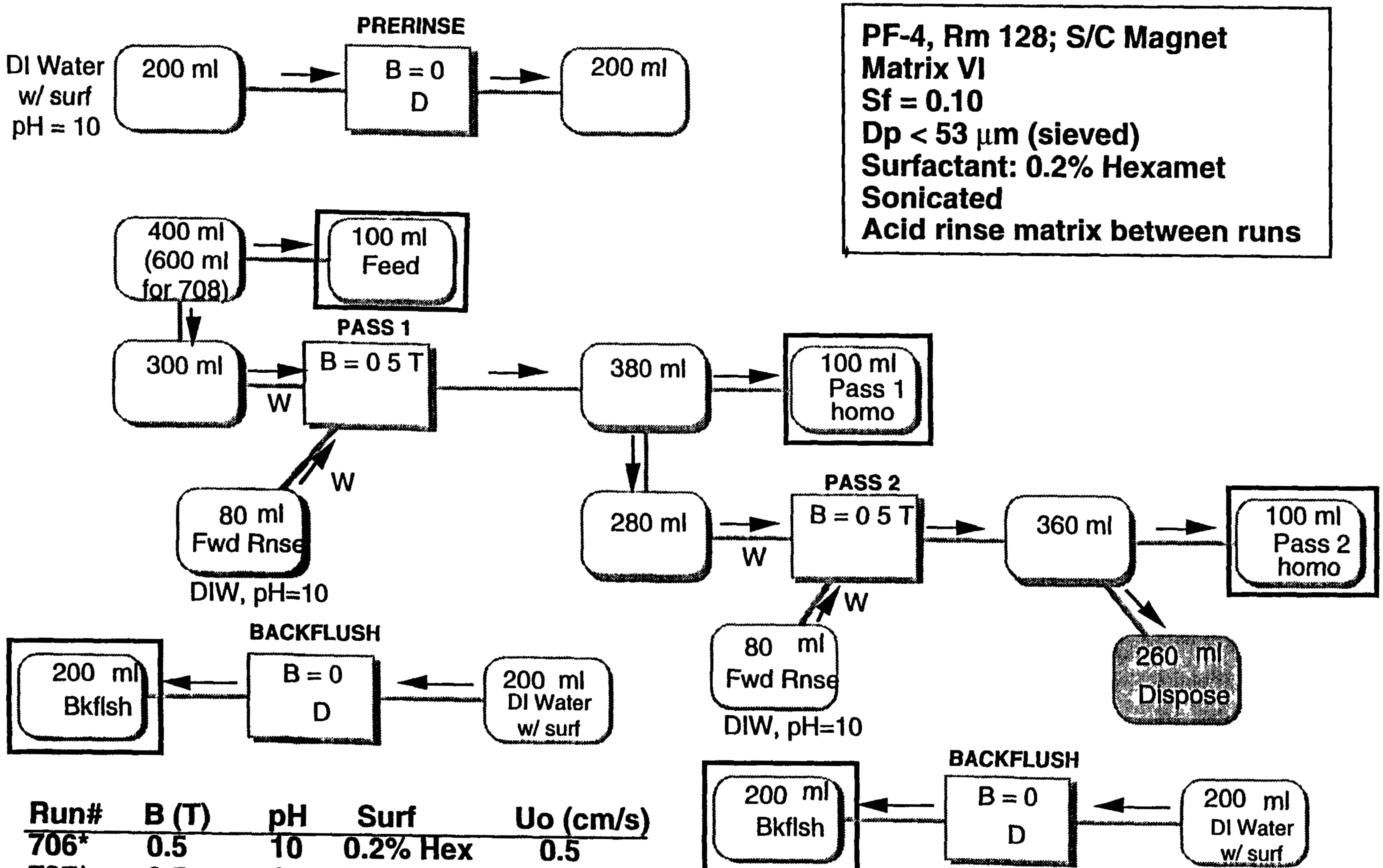
DATA

Test #	Pass #	Displayed Flow Rate (ml/s)	Corrected Flow Rate (ml/s)	Magnet Current (A)	Field Strength (Tesla)	Solids Conc (%)	Temp (C)	Flow Direction
706 0	0	-	-	0	0	10%	20	-
706 0	0	-	-	0	0	10%	20	-
706 1	1	70	1 35	16 9	2	10%	20	D
706 1b	1	400	7 5	0	0	10%	20	U
706 2	2	70	1 35	16 9	2	10%	20	D
706 2b	2	400	7 5	0	0	10%	20	U
707 0	0	-	-	0	0	10%	20	-
707 1	1	70	1 35	16 9	2	10%	20	D
707 1b	1	400	7 5	0	0	10%	20	U
707 2	2	70	1 35	16 9	2	10%	20	D
707 2b	2	400	7 5	0	0	10%	20	U
708 0	0	-	-	0	0	10%	20	-
708 1	1	70	1 35	16 9	2	10%	20	D
708 1b	1	400	7 5	0	0	10%	20	U
708 2	2	70	1 35	16 9	2	10%	20	D
708 2b	2	400	7 5	0	0	10%	20	U
708 3	3	70	1 35	16 9	2	10%	20	D
708 3b	3	400	7 5	0	0	10%	20	U
709 0	0	-	-	0	0	10%	20	-
709 1	1	70	1 35	16 9	2	10%	20	D
709 1b	1	400	7 5	0	0	10%	20	U
709 2	2	70	1 35	16 9	2	10%	20	D
709 2b	2	400	7 5	0	0	10%	20	U

4/22/94 RFP Sample (LESAT Residue - Thickener underflow)

Determine effect of flowrate, pH and H2O2 pretreatment

PF-4, Rm 128; S/C Magnet
Matrix VI
Sf = 0.10
Dp < 53 µm (sieved)
Surfactant: 0.2% Hexamet
Sonicated
Acid rinse matrix between runs



Run#	B (T)	pH	Surf	Uo (cm/s)
706*	0.5	10	0.2% Hex	0.5
707*	0.5	12	0.2% Hex	0.5
708**	0.5	10	0.2% Hex	1.0
709***	0.5	10	0.2% Hex	0.5

* Pass 2 w/ activated magnetite added
**Acid rinse matrix after pass 1; collect 2 feeds & 2 pass 2 effluents
***With H2O2 pretreatment for organics

Sample	Weight	Mass Balance Error	Mass Fraction	Specific Activity	Activity	Activity Balance Error	Mass Weighted Specific Activity	Separation Efficiency* Using		
	(g)	(%)		(pCi/g)	(pCi)	(%)	(pCi/g)	feed & bk	bk & effl	feed & effl
Run #706										
feed	50			68 3	3415 00					
XXX.0	18 46			68 3	1260 82					
Pass 1 feed	31 54		1 000	68 3	2154 18		68 300			
XXX.1	7 24			80 4	582 10					
XXX.1f	1 51		0 048	19 4	29 29		0 929			
XXX.1b	2 54		0 081	19 4	49 28		1 562	0 023	0 022	-0 040
Pass 1 eff	27 49		0 872	80 4	2210 20		70 076			
Pass 2 feed	20 25		1 000	80 4	1628 10		80 400			
XXX.2	5 31			118	626 58					
XXX.2f	0 66		0 033	32 4	21 38		1 056			
XXX.2b	6 05		0 299	120 00	726 00		35 852	0 494	0 310	0 006
Pass 2 eff	13 54		0 669	118 00	1597 72		78 900			
XXX 2e	12			118 00	1416 00					
Total	53 77	7 54	**0.379**		4711 45	37 96		0 506	0 324	-0 034
Run #707										
feed	38 75			94	3642 50					
XXX 0	8 16			94	767 04					
Pass 1 feed	30 59		1 000	94	2875 46		94 000			
XXX.1	5 56			99 1	551 00					
XXX.1f	1 56		0 051	17	26 52		0 867			
XXX 1b	2 78		0 091	31 6	87 85		2 872	0 031	0 032	0.086
Pass 1 eff	26 25		0 858	99 1	2601 38		85 040			
Pass 2 feed	20 69		1 000	99 1	2050 38		99 100			
XXX.2	5 22			73 5	383 67					
XXX.2f	1 17		0 057	65 7	76 87		3 715			
XXX.2b	4 71		0 228	92 20	434 26		20 989	0 209	0 271	0 432
Pass 2 eff	14 81		0 716	73 50	1088 54		52 612			
XXX.2e	9 1			73 50	668 85					
Total	38 26	-1 26	**0 319**		2996 06	-17 75		0 234	0 295	0 481

Sample	Weight	Mass Balance Error	Mass Fraction	Specific Activity	Activity	Activity Balance Error	Mass Weighted Specific Activity	Separation Efficiency* Using		
	(g)	(%)		(pCi/g)	(pCi)	(%)	(pCi/g)	feed & bk	bk & effl	feed & effl
Run #708										
feed	38 75			81	3138 75					
XXX.0	8 16			81	660.96					
Pass 1 feed	30 59		1 000	81	2477 79		81 000			
XXX.1	6.83			32 8	224 02					
XXX.1f	0 76		0 025	35 2	26 75		0 875			
XXX.1b	1 53		0 050	57 1	87 36		2 856	0 035	0 084	0 615
Pass 1 eff	28 3		0 925	32 8	928 24		30 345			
Pass 2 feed	21 47		1 000	32 8	704 22		32 800			
XXX.2	4 96			94 2	467 23					
XXX.2f	0 62		0 029	93 2	57 78		2 691			
XXX.2b	4 65		0 217	76 10	353 87		16 482	0 200	0 183	-1 249
Pass 2 eff	16 2		0 755	94 20	1526 04		71 078			
Pass 3 feed	11 24		1 000	94 2	1058 81		94 200			
XXX 3	3 8		-	73 70	280 06					
XXX.3f	0 9		0 080	33 5	30 15		2 682			
XXX.3b	3 16		0 281	86 30	272 71		24 262	0 289	0 328	0 472
Pass 3 eff	7 18		0 639	73 70	529 17		47 079			
XXX.3e	3 49			73 70	257 21					
Total	38 86	0 28	**0.548**		2718 11	-13 40		0 451	0 497	0 542
Run #709										
feed	50			96 1	4805 00					
XXX.0	12 5			96 1	1201 25					
Pass 1 feed	37 5		1 000	96 1	3603 75		96 100			
XXX.1	9 49			85 9	815 19					
XXX 1f	2 3		0 061	20 1	46 23		1 233			
XXX.1b	2 11		0 056	48 4	102 12		2 723	0 028	0 034	0 198
Pass 1 eff	33 09		0 882	85 9	2842 43		75 798			
Pass 2 feed	23 6		1 000	85 9	2027 24		85 900			
XXX.2	8 03			87 4	701 82					
XXX.2f	1 19		0 050	50	59 50		2 521			
XXX.2b	6 29		0 267	152 00	956 08		40 512	0 409	0 394	0 276
Pass 2 eff	16 12		0 683	87 40	1408 89		59 699			
Pass 3 feed	11 24		1 000	87 4	982 38		87 400			
XXX.3	5 29			70 20	371 36					
XXX.3f	1 29		0 115	2016	2600 64		231 374			
XXX.3b	3 64		0 324	18 00	65 52		5 829	0 073	0 021	-2 098
Pass 3 eff	6 31		0 561	70 20	442 96		39 409			
XXX.3e	2 91			70 20	204 28					
Total	55 04	10 08	**0.647**		7124 00	48 26		0 468	0 427	-0 799

$$\frac{\text{*(Mass Fraction *Specific Activity)mags}}{\text{(Mass Fraction *Specific Activity)feed}}$$

Combined efficiencies are calculated using* Etot = E1 + E2 - E1*E2 or

Forward flushes (XXX Xf) are combined with effluent when calculating efficiencies

*Note for three passes efficiencies are calculated as follows
Etot = E1+E2+E3 - E1*E2 - E1*E3 - E2*E3 + E1*E2*E3

MAGNETIC SEPARATION TEST

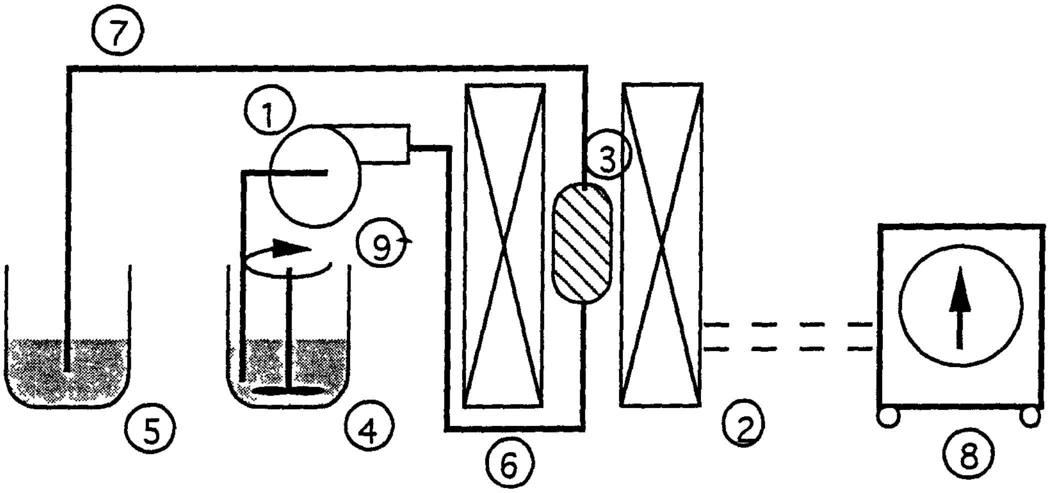
Date- 9/15/94 Location-TA55/PF4/RM128

Separator-

Type	Magnet	Manufacturer	Descriptor
HGMS	3" Superconductor	Cryomagnetics	Internal

Objective-Test Series 3

Experimental Schematic-



(1) Monostat D Series Varistatlic pump calibrated for tubing with 4 layers of tape in tube tray and foam to center tubing in tray
(2) Cyomagnetics 3" warm bore S/C magnetic separator
(3) Matrix
(4) Supply beaker
(5) Exit and sample beaker
(6) Nalgene tubing 1/8" ID
(7) Nalgene tubing 1/8" ID
(8) Magnet power supply
(9) Stirrer

MAGNETIC SEPARATION TEST   RFP Soil LESAT Residue

Date 9/15/94

Carrier Flui

Description
DI H2O

Surrogate

Description	Particle Size
LESAT Thickner Underflow	<53u

Matrix

pass 1 Matrix VII
pass 2 Matrix VIII

Comments

Test	pH	Sf	Surf
710	10	0 1	2% hex
711	10	0 05	2% hex
712	10	0 1	2% hex
713	10	0 1	Sodium Silicate

DATA

Test #	Pass #	Displayed Flow Rate (ml/s)	Corrected Flow Rate (ml/s)	Magnet Current (A)	Field Strength (Tesla)	Solids Conc (%)	Temp (C)	Flow Direction
710 0	0	-	-	0	0	5%	20	-
710 1	1	70	1 35	16 9	2	5%	20	D
710 1f	1	70	1 35	16 9	2	5%	20	D
710 1b	1	400	7 5	0	0	5%	20	U
710 2	2	70	1 35	3 8	0 5	5%	20	D
710 2f	2	70	1-35	3 8	0 5	5%	20	D
710 2b	2	400	7 5	0	0	5%	20	U
710 3	3	70	1 35	56	6 5	5%	20	D
710 3f	3	70	1 35	56	6 5	5%	20	D
710 3b	3	400	7 5	0	0	5%	20	U
711 0	0	-	-	0	0	5%	20	-
711 1	1	70	1 35	16 9	2	5%	20	D
711 1f	1	70	1 35	16 9	2	5%	20	D
711 1b	1	400	7 5	0	0	5%	20	U
711 2	2	70	1 35	3 8	0 5	5%	20	D
711 2f	2	70	1 35	3 8	0 5	5%	20	D
711 2b	2	400	7 5	0	0	5%	20	U
711 3	3	70	1 35	56	6 5	5%	20	D
711 3f	3	70	1 35	56	6 5	5%	20	D
711 3b	3	400	7 5	0	0	5%	20	U
712 0	0	-	-	0	0	5%	20	-
712 1	1	70	1 35	16 9	2	5%	20	D
712 1f	1	70	1 35	16 9	2	5%	20	D
712 1b	1	400	7 5	0	0	5%	20	U
712 2	2	70	1 35	3 8	0 5	5%	20	D
712 2f	2	70	1 35	3 8	0 5	5%	20	D
712 2b	2	400	7 5	0	0	5%	20	U
712 3	3	70	1 35	56	6 5	5%	20	D
712 3f	3	70	1 35	56	6 5	5%	20	D
712 3b	3	400	7 5	0	0	5%	20	U

MAGNETIC SEPARATION TEST **RFP Soil LESAT Residue**

Date 9/15/94

Carrier Flui

Description
DI H2O

Surrogate

Description	Particle Size
LESAT Thickner Underflow	<53u

Matrix

pass 1 Matrix VII
pass 2 Matrix VIII

Comments

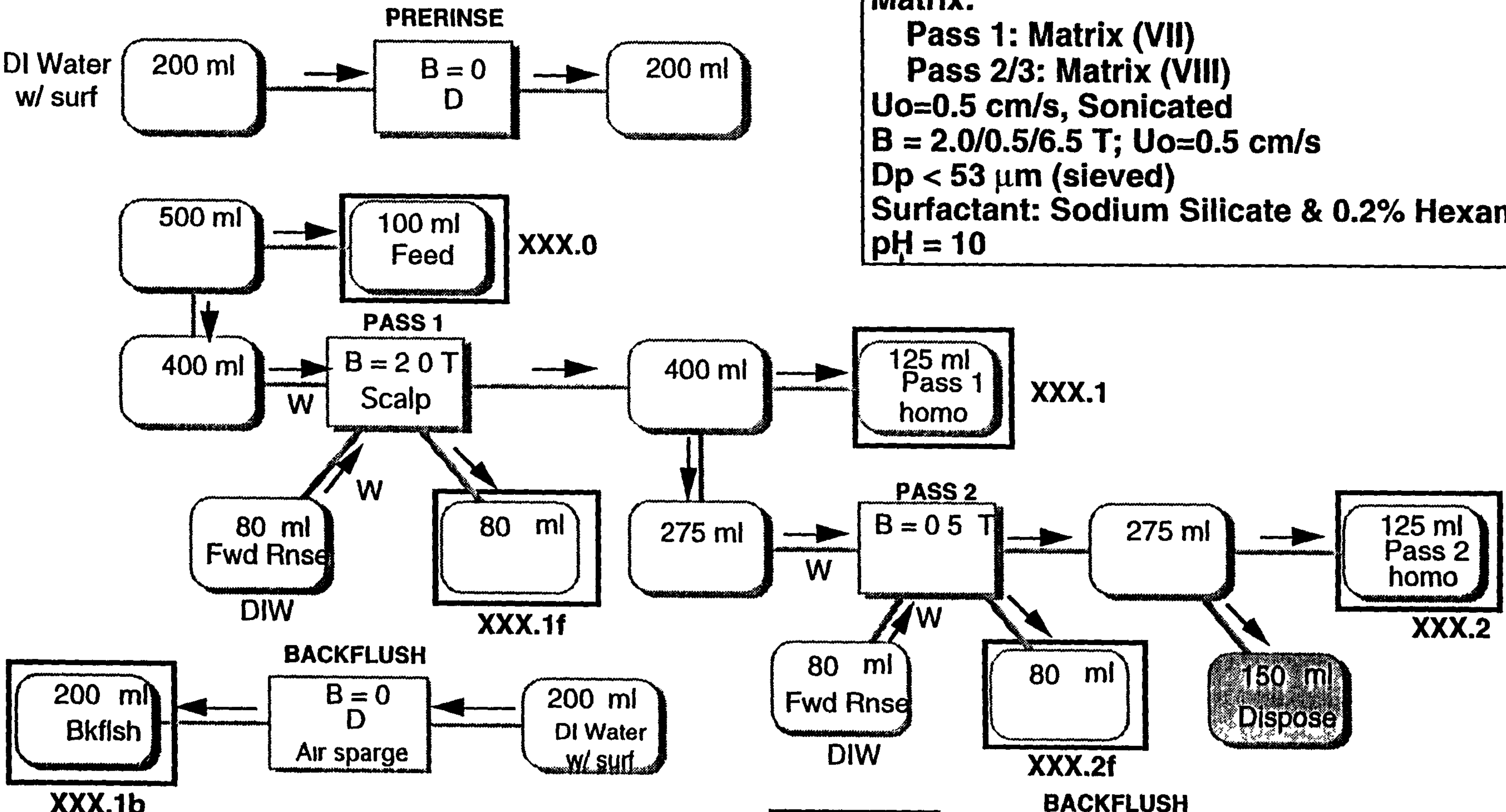
Test	pH	Sf	Surf
710	10	0 1	2% hex
711	10	0 05	2% hex
712	10	0 1	2% hex
713	10	0 1	Sodium Silicate

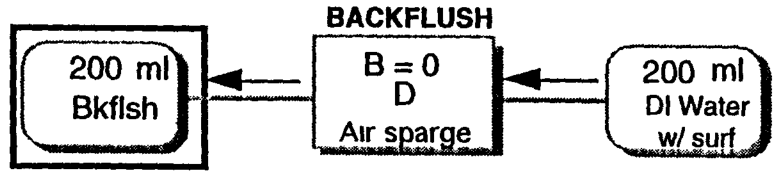
713 0	0	-	-	0	0	5%	20	-
713 1	1	70	1 35	16 9	2	5%	20	D
713 1f	1	70	1 35	16 9	2	5%	20	D
713 1b	1	400	7 5	0	0	5%	20	U
713 2	2	70	1 35	3 8	0 5	5%	20	D
713 2f	2	70	1 35	3 8	0 5	5%	20	D
713 2b	2	400	7 5	0	0	5%	20	U
713 3	3	70	1 35	56	6 5	5%	20	D
713 3f	3	70	1 35	56	6 5	5%	20	D
713 3b	3	400	7 5	0	0	5%	20	U

9/15/94 RFP Sample (LESAT Residue - Thickener underflow)

Determine effect of Surfactant and H2O2 pretreatment

PF-4, Rm 128; S/C Magnet
Matrix:
Pass 1: Matrix (VII)
Pass 2/3: Matrix (VIII)
Uo=0.5 cm/s, Sonicated
B = 2.0/0.5/6.5 T; Uo=0.5 cm/s
Dp < 53 μm (sieved)
Surfactant: Sodium Silicate & 0.2% Hexamet
pH = 10





Run#	B (T)	pH	Surf	Sf
710**	2.0/0.5/6.5	10	0.2% Hex	0.1
711	2.0/0.5/6.5	10	0.2% Hex	0.05
712*	2.0/0.5/6.5	10	0.2% Hex	0.1
713	2.0/0.5/6.5	10	Sodium Silicate	0.1

All runs have 3rd Pass at 6.5 T
*With H2O2 pretreatment for organics
**Replaced hoses between passes

Sample	Weight	Mass Balance Error	Mass Fraction	Specific Activity	Activity	Activity Balance Error	Mass Weighted Specific Activity	Separation Efficiency* Using		
	(g)	(%)		(pCi/g)	(pCi)	(%)	(pCi/g)	feed & bk	bk & effl	feed & effl
Run #710										
feed	55 50			132 00	7326 00					
XXX.0	11 40			132 00	1504 80					
Pass 1 feed	44 10		1 000	132 00	5821 20		132 000			
XXX.1	10 96			77 40	848 30					
XXX.1f	4 60		0 104	89 60	412 16		9 346			
XXX.1b	4 86		0 110	96 50	468 99		10 635	0 081	0 132	0 469
Pass 1 eff	34 64		0 785	77 40	2681 14		60 797			
Pass 2 feed	23 68		1 000	77 40	1832 83		77 400			
XXX.2	8 00			134 30	1074 40					
XXX.2f	2 08		0 088	90 90	189 07		7 984			
XXX 2b	4 16		0 176	170 50	709 28		29 953	0 220	0 219	-0 381
Pass 2 eff	17 44		0 736	134 30	2342 19		98 910			
Pass 3 feed	11 24		1 000	134 30	1509 53		134 300			
XXX.3	2 60			130 50	339 30					
XXX 3f	1 20		0 107	73 48	88 18		7 845			
XXX.3b	5 00		0 445	153 60	768 00		68 327	0 529	0 507	0 506
Pass 3 eff	5 04		0 448	130 50	657 72		58 516			
XXX.3e	0 00			130 50	0 00					
Total	54 86	-1 15	**0 731**		6402 48	-12 61		0 662	0 666	0 637
Run #711										
feed	27.75			99 98	2774 45					
XXX.0	6 66			99 98	665 87					
Pass 1 feed	21 09		1 000	99 98	2108 58		99 980			
XXX.1	4 75			164 50	781 38					
XXX.1f	3 30		0 156	96 60	318 78		15 115			
XXX.1b	2 60		0 123	42 25	109 85		5 209	0 052	0 038	-0 336
Pass 1 eff	15 19		0 720	164 50	2498 76		118 481			
Pass 2 feed	10 44		1 000	164 50	1717 38		164 500			
XXX.2	3 31			163 10	539 86					
XXX.2f	1 44		0 138	68 50	98 64		9 448			
XXX.2b	2 97		0 284	120 40	357 59		34 252	0 317	0 248	0 370
Pass 2 eff	6 03		0 578	163 10	983.49		94.204			
Pass 3 feed	11 24		1 000	163 10	1833 24		163 100			
XXX.3	1 30			166 17	216 02					
XXX.3f	0 50		0 044	51 91	25 96		2 309			
XXX.3b	2 00		0 178	96 70	193 40		17 206	0 167	0 116	0 194
Pass 3 eff	8 74		0 778	166 17	1452 33		129 210			
XXX.3e	0 00			166 17	0 00					
Total	28 83	3 89	**0.586**		3307 34	19 21		0 460	0 360	0 321

35

Sample	Weight	Mass Balance Error	Mass Fraction	Specific Activity	Activity	Activity Balance Error	Mass Weighted Specific Activity	Separation Efficiency* Using		
	(g)	(%)		(pCi/g)	(pCi)	(%)	(pCi/g)	feed & bk	bk & effl	feed & effl
Run #712										
feed	50 00			113 30	5665 00					
XXX.0	12 80			113 30	1450 24					
Pass 1 feed	37 20		1 000	113 30	4214 76		113 300			
XXX.1	10 00			73 20	732 00					
XXX 1f	4 20		0 113	71 70	301 14		8 095			
XXX.1b	3 10		0 083	50 27	155 84		4 189	0 037	0 059	0 409
Pass 1 eff	29 90		0 804	73 20	2188 68		58 835			
Pass 2 feed	19 90		1 000	73 20	1456 68		73 200			
XXX 2	6 90			133 20	919 08					
XXX 2f	2 80		0 141	86 70	242 76		12 199			
XXX.2b	3 60		0 181	77 95	280 62		14 102	0 118	0 121	-0 401
Pass 2 eff	13 50		0 678	133 20	1798 20		90 362			
Pass 3 feed	11 24		1 000	133 20	1497 17		133 200			
XXX 3	2 30			186 70	429 41					
XXX 3f	0 40		0 036	66 41	26 56		2 363			
XXX 3b	2 40		0 214	48 69	116 86		10 396	0 081	0 068	-0 070
Pass 3 eff	8 44		0 751	186.70	1575 75		140 191			
XXX.3e	0 00			186 70	0 00					
Total	48 50	-3 00	**0 478**		4654 51	-17 84		0 220	0 229	0 114
Run #713										
feed	55 50			76 80	4262 40					
XXX.0	13 06			76 80	1003 01					
Pass 1 feed	42 44		1 000	76 80	3259 39		76 800			
XXX 1	10 40			115 20	1198 08					
XXX.1f	5 00		0 118	48 60	243 00		5 726			
XXX 1b	4 70		0 111	53 79	252 81		5 957	0 078	0 059	-0 232
Pass 1 eff	32 74		0 771	115 20	3771 65		88 870			
Pass 2 feed	22 34		1 000	115 20	2573 57		115 200			
XXX.2	6 92			89 00	615 88					
XXX.2f	3 45		0 154	36 48	125 86		5 634			
XXX.2b	5 90		0 264	145 10	856 09		38 321	0 481	0 400	0 502
Pass 2 eff	12 99		0 581	89 00	1156.11		51.751			
Pass 3 feed	11.24		1 000	89 00	1000 36		89 000			
XXX.3	1 40			62 15	87 01					
XXX.3f	1 40		0 125	33 37	46 72		4 156			
XXX 3b	6 80		0 605	128 55	874 14		77 770	1 384	0 788	0 764
Pass 3 eff	3 04		0 270	62.15	188 94		16 809			
XXX 3e	0 00			62 15	0 00					
Total	59 03	6 36	**0 980**		5302 60	24 40		1 184	0 880	0 855

Je

$$\frac{*(\text{Mass Fraction} * \text{Specific Activity})_{mags}}{(\text{Mass Fraction} * \text{Specific Activity})_{feed}}$$

Combined efficiencies are calculated using* Etot = E1 + E2 - E1*E2

Forward flushes (XXX Xf) are combined with effluent when calculating efficiencies

*Note for three passes efficiencies are calculated as follows:
Etot = E1+E2+E3 - E1*E2 - E1*E3 - E2*E3 + E1*E2*E3